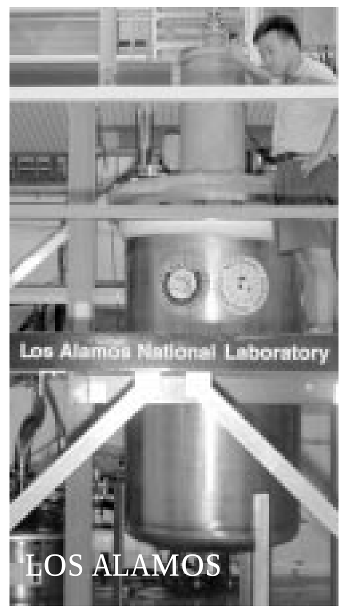
User Facilities

Chapter 2

The research activities described in the previous chapter of this annual report are supported by the extensive facilities of the National High Magnetic Field Laboratory. Each of the consortium partners—Florida State University (FSU), the University of Florida (UF), and Los Alamos National Laboratory (LANL)—offers outstanding resources for users, but collectively, the three sites offer members of the worldwide science and engineering communities unprecedented opportunities to explore science at the extremes of magnetic field, pressure, and temperature.



The facilities and activities of the laboratory located at FSU in Tallahassee are housed in a modern, 330,000 sq. ft. complex dedicated to research and technology related to high magnetic fields. Superconducting, resistive, hybrid, and specialty user magnets are located at this site, along with most of the Magnet Science and Technology Group, the Center for Interdisciplinary Magnetic Resonance (CIMAR), the Research Program, and the administrative headquarters of the NHMFL. The NHMFL Pulsed Field Facility is located at LANL in New Mexico; and the High B/T (magnetic field/temperature) Facility and the magnetic resonance imaging/spectroscopy (MRI/S) assets of the laboratory are located in the Advanced Magnetic Resonance Imaging and Spectroscopy (AMRIS) Facility at UF in Gainesville. In addition to the "hardware" assets of the laboratory (presented in the following table), the close proximity of visiting users to the distinguished NHMFL faculty and the affiliated faculty at the three institutions sets the stage for very productive collaborations and cross-disciplinary scientific exchanges.

Table 1. Magnet systems of the National High Magnetic Field Laboratory.

RESISTIVE and HYBRID MAGNETS*

FIELD (T), BORE (mm)	POWER (MW)	SUPPORTED RESEARCH
45, 32+ 33, 32◊ 30, 32 25, 52# 24.5, 32# 20, 195	~20 19 15 20 15 20	Magneto-optics (ultra-violet through far infrared), magnetization, specific heat, transport, high pressure, NMR in highest fields (low to medium resolution), EMR

SUPERCONDUCTING MAGNETS

FIELD (T), BORE (mm)	TEMPERATURE	SUPPORTED RESEARCH
20, 52* 19.5, 52* 15, 45* 6, 100*	20 mK - 2 K 0.4 - 300 K 10 mK - 1 K 1.8 K - 300 K	Magneto-optics (ultra-violet through far infrared), magnetization, specific heat, transport, high pressure, NMR in highest fields (low to medium resolution)
13,150* (30x70 mm split)	4.2 K	Large magnet component testing
19.5, 52**	20 mK to 500 K	Magneto-optics (ultra-violet through near infrared), magnetization, mechanical properties, thermal expansion, specific heat, transport, high pressure, NMR in highest fields (low to medium resolution)
20, 30***	0.4 mK	Quantum Hall effect, transport measurements in dilute ^3He-^4He mixtures, ordered phases in solid ^3He

PULSED MAGNETS**

FIELD (T), BORE (mm)	RISE, DECAY TIME (ms)	SUPPORTED RESEARCH
50, 24 60, 24+ 62, 15 70, 10+ 45, 24# 42, 24	6, 30 7, 35 9, 60 100, 500	Magneto-optics (ultra-violet through near infrared), magnetization, transport, high pressure, NMR in highest fields (low resolution)
60, 32	1000, 1000 (with 100 msec flat-top)	User-controlled pulse shape enables, for example, measurements of specific heat

USER FACILITIES

MAGNETIC RESONANCE SYSTEMS

FREQUENCY	FIELD (T), BORE (mm)	HOMOGENEITY	MEASUREMENTS
1066 MHz*#	25, 52	1 ppm	Solid state NMR
900 MHz*+	21.1, 110	1 ppb	NMR and MRI
830 MHz*#◊	19.6, 31	100 ppb	Solid state NMR
750 MHz***+	17.6, 89	1 ppb	Solution state NMR, MRI/S
720 MHz*	16.9, 50	1 ppb	Solution state NMR
600 MHz*	14, 89	1 ppb	MRI and solid state NMR
600 MHz***	14, 50	1 ppb	Solution state NMR MRI/S
500 MHz*	11.75, 50	1 ppb	Solution state NMR
500 MHz***	11.75, 50	1 ppb	Solid and solid state NMR
500 MHz***+	11.75, 400	0.1 ppm	MRI/S of animals
500 MHz***+	11.75, 50	1 ppb	Solution state NMR
400 MHz*	9.3, 50	1 ppb	Solution state NMR with high Tc probe
300 MHz*	7, 50	1 ppb	Solution state NMR
300 MHz*	7, 89	1 ppb	Solid state NMR
200 MHz***	4.7, 330	0.1 ppm	MRI/S of animals
125 MHz***	3, 800	0.1 ppm	Whole body MRI/S
Up to 7 THz*	30, 32	100 ppm	ECR
700 GHz*#◊	25, 52	1 ppm	Multifrequency EMR
470 GHz*	17, 61	3 ppm	Multifrequency EMR
400 GHz+	14, 88	3 ppm	Transient EMR
9 GHz*			X-band EPR
	25, 52*#	1 ppm	ICR MS
	15, 110*+	1 ppm	ICR MS
	11, 210*+	1 ppm	ICR MS
	9.4, 210*◊	1 ppm	ICR MS
	7, 150*	2 ppm	ICR MS
	6, 150*	10 ppm	ICR MS
	3, 150*	10 ppm	ICR MS

GEOCHEMISTRY MASS SPECTROMETERS*

TYPE OF IONIZATION	MASS ANALYZER CONFIGURATION	DETECTION SYSTEMS	MEASUREMENT	SAMPLE INTRODUCTION
Thermal and Sputtering	E-M-D1-E-D2	D1: 4 Faraday cups after M D2: Daly Ion counting and Faraday cup	Isotope ratios: Th, Hf and Hg	Solids and chemical separates
Thermal	M-D1-E-D2	D1: 7 Farady cups, 1 electron multiplier D2:Electron multiplier	Isotope ratios: Pb, Sr, Nd, Os	Chemical separates
Thermal-Plasma	M-E-D	D: Electron multiplier	Concentrations and isotope ratios	Solutions

*=Tallahassee
**=Los Alamos
***=Gainesville
+=Under development
#=Higher homogeneity magnet
◊=Highest performing system of its kind in the world
E=Energy filter
M=Magnetic mass filter

USER FACILITIES

The NHMFL at Florida State University, Tallahassee

Continuous Field Facility

The DC facilities in Tallahassee have a unique and extremely powerful infrastructure—a 36 MW DC power supply with ripple and noise approaching 10 ppm and an overload capacity to 40 MW for an hour or 68 MW for several minutes. The complex also has a very low vibration cooling system that is especially important for experiments with very small signals. The Continuous Field Facility offers extensive support capabilities, including a machine shop, an electronics shop, and computer support.

The continuous field magnet systems available or under development (as described in the table) include resistive, superconducting, and hybrid magnets. The world's highest continuous field resistive magnets—33 T in a 32 mm bore—are located in this facility, as well as 24.5 T, 32 mm bore, high homogeneity magnets that have proven to be extremely useful tools for magnetic resonance research. A 25 T, 52 mm bore Bitter magnet with 1 ppm homogeneity and stability is available for magnetic resonance experiments. It was developed and is being improved with funding from the NSF and the Keck Foundation. A very large bore—20 T, 195 mm—magnet is available for superconducting magnet coil tests, ion cyclotron resonance, two-axis sample rotation, long-path magneto optics, very high temperatures, and other experiments that will not fit into the other magnets. The 45 T, 32 mm bore, hybrid magnet is expected to be operational in 1999. This magnet comprises a 14 T, 610 mm, warm bore, cable-in-conduit, superconducting outsert with a 24 MW, 31 T, resistive insert.

Instrumentation to support the kinds of research listed in the table is available along with people to assist scientists with their experiments. Complete descriptions of the instrumentation are available on the Users pages of the NHMFL web site at *http://www.nhmfl.gov/users*, or by sending e-mail to *brandt@magnet.fsu.edu*.

Magnetic Resonance Facilities

The NHMFL's Center for Interdisciplinary Magnetic Resonance (CIMAR) was established in 1994 to support studies in nuclear magnetic resonance (NMR), magnetic resonance imaging (MRI), electron magnetic resonance (EMR), and ion cyclotron resonance (ICR). A unique feature of CIMAR is the large-scale integration of NMR, MRI, EMR, and ICR spectroscopies. Cross-fertilization among these fields is facilitated at the laboratory in several ways through a broad-based external and internal users program. The magnetic resonance program spans all three NHMFL sites with the primary facilities for NMR, EMR, and ICR in Tallahassee and the primary facilities for MRI and *in vivo* spectroscopy in Gainesville (see later in this section).

A variety of NMR systems is available in Tallahassee, as detailed in the table. Several systems have been or are being improved:

- The 720 MHz is being upgraded with a fourth radio frequency (RF) channel.
- A triple resonance magic angle spinning (MAS) probe for both slow and fast spinning has been ordered for the 89 mm, 600 MHz spectrometer, complementing the imaging and diffusion capabilities as well as double resonance solids capabilities of this magnet.
- A 400 MHz, 89 mm bore system is outfitted with a superconducting probe for solution NMR.
- A triple resonance console, MAS and static probes have been ordered for the 31 mm bore, 830 MHz system.
- The 25 T resistive magnet (the Keck magnet) has a 52 mm bore and 1 ppm stability. Static MAS and double axis rotation (DOR) probes are being built and the homogeneity is anticipated to be better than 1 ppm over a 1 cm diameter spherical volume.

EMR, which includes electron paramagnetic resonance (EPR) and electron cyclotron resonance (ECR), is conducted in both resistive and superconducting magnets. Highlighting the EMR program are the 700 GHz spectrometer for the "Keck" resistive magnet and the 400 GHz transient EMR machine, which is under development. The 700 GHz instrument is the highest frequency/field machine in the world. The 400 GHz transient machine will be unique and will allow the study of fast phenomena in the sub nanosecond range, which is of paramount interest in photosynthesis for instance.

The centerpiece of the ICR program is a 9.4 T, 1 ppm, 220 mm warm bore, shielded superconducting Oxford magnet system. This is the highest performance system of its kind in the world, offering users unparalleled opportunities to identify and characterize large molecules including peptides, proteins, oligosaccharides, and nucleic acids. In addition, ICR systems at 11 T and 17 T are under construction.

The NHMFL, in partnership with Intermagnetics General, is developing a 900 MHz (21.1 T) high resolution magnet system for NMR. This wide bore (100 mm inner diameter) system is expected to be completed in late 1999, thus providing the highest field large bore NMR system in the world. The design of this system also will serve as a platform for the incorporation of a high temperature superconducting insert magnet that will provide the combined field of 25 T (1.067 GHz).

Geochemistry Facilities

The mass spectrometry facility includes a better-than-Class 500 wet chemistry clean laboratory. This lab is used for the separation and purification of all elements that are analyzed by solid source mass spectrometry. In addition, the facility has two vacuum lines used for separation and purification of samples for light stable isotope analysis. The facility has three mass spectrometers providing a unique combination of ionization techniques: sputtering and thermal ionization as well as ionization in a plasma source. The Lamont Isolab, the only one of its kind in the United States, is outfitted with a Daly detection system and 5 Faraday cups, and has thermal ionization and secondary ionization capability.

The facility includes a fully automated, 7 collector, Finnigan MAT 262, mass spectrometer equipped with a retarding potential quadrupole for increased abundance sensitivity and a 13 sample turret. This second mass spectrometer is to be used for Sr, Nd, Pb, and U isotope ratio analyses by positive thermal ionization and Re and Os by negative ionization, as well as for most isotope dilution analyses.

The third mass spectrometer is a high resolution inductive coupled plasma mass spectrometer (ICP-MS). This instrument represents a new generation of ICP-MS as the mass analyzer is a magnetic sector instead of a conventional quadrupole magnet resulting in superior mass resolution and transmission. This instrument is used for low level trace element analysis as well as isotope ratio analysis.

Materials Characterization Facility

These facilities provide testing and analysis services to NHMFL magnet design teams as well as industrial and academic researchers. The laboratory provides precise measurements of electrical resistivity, thermal expansion, and superconductor critical current. Mechanical properties such as tensile, compressive, fatigue, and shear strength also can be measured. There are three servo-hydraulic test machines for performing mechanical tests over a range of temperatures (1.8 K to 400 K). Two superconducting magnets can provide background fields of up to 15 T in conjunction with mechanical and electrical tests.

The Large Magnet Component Test Facility (LMCTF) is primarily dedicated to the testing of composite conductor cables for large magnets such as the superconducting segment of the 45 T Hybrid, as well as for magnets for fusion, energy storage, and high energy physics. The laboratory houses cryogenic test facilities for measurement of critical current vs. transverse stress, AC loss, thermal stability and quench propagation. Superconducting magnets are available with bore sizes and field strengths ranging from a 50 mm, 1 m long, 7 T (dipole) used for AC loss measurements to a 2 m cold bore, 4 T solenoid for Navy superconducting magnetic energy storage (SMES) testing. A variety of large, high-current electrical equipment is available to support testing in the LMCTL, including the 36 MW, 76 kA DC magnet power supply and connection to the ±20 V, 12 kA Hybrid outsert power supply.

The NHMFL at Los Alamos National Laboratory

Pulsed Field Facility

LANL is home to the NHMFL's Pulsed Field Facility because of that laboratory's unique facilities for the production of pulsed electrical power and the dedicated sites for flux compression experiments. The Pulsed Field Facility is supported by a capacitor bank of 1.2 MJ and a motor generator capable of delivering an energy pulse of 600 MJ. The motor generator can be upgraded to 2000 MJ with the addition of a flywheel and power supply modules.

A variety of pulsed magnet systems are available at NHMFL-Los Alamos including 50 T and 63 T capacitor driven magnets with 24 mm and 15 mm bores, respectively. All of these systems are equipped with an assortment of inserts (dilution refrigerator, He-3, and variable temperature) and instrumentation that supports transport, magnetization, high pressure, and optics studies. Four magnet stations, collaborative opportunities, and user support are available.

A 60 T, 32 mm bore, long pulse magnet was commissioned in 1998 and set a new world record, 60 T, for this type of magnet. Besides being the most powerful of its class in the world, this magnet is also the first of its kind in the United States. It promises to be a significant new research tool. In-house users began developing instruments and techniques in late 1997, and requests for magnet time from industrial and university users from around the world have been high.

One of the key features of the new 60 T long pulse magnet at the NHMFL is the incredible flexibility offered to experimentalists to tailor the magnetic field pulse shape in response to the demands of the experiment. The magnet can be pulsed every hour, and the magnetic field pulse shape can be changed from pulse to pulse at the wishes of the experimentalist. Pulse shapes already delivered to experiments include "flat top" pulses in which the magnetic field has been held constant at 60 T for as long as 100 milliseconds (ms), at 50 T for 200 ms, and at 40 T for 500 ms. Smooth magnetic field sweeps from 60 T down to 0 T have been demonstrated to last more than two seconds. More recently, stair-step pulse shapes have been developed for specific heat measurements (see "Attention Users" in *NHMFL Reports*, Fall 1998).

In addition to systems currently available, a non-destructive 100 T (24 mm bore), 20 ms to 50 ms pulsed magnet is being developed by the NHMFL and LANL as a jointly-funded effort between the U.S. Department of Energy and the National Science Foundation.

A 19.5 T superconducting magnet with 52 mm bore is also available. This magnet is equipped with a variety of probes, including: dilution refrigerator, variable temperature inserts, and high temperature insert allowing experiments from 20 mK to 500 K. This magnet not only serves as a staging magnet for calibration purposes for pulse field experiments but also works as an excellent tool for measuring magnetotransport, heat capacity, thermal expansion, and magnetostriction in a wide temperature range.

Flux Compression Experimental Areas

Academic and industrial researchers may access the unique magnetic flux compression experimental areas at LANL through a cooperative arrangement with the NHMFL. The flux compression technique employs chemical explosives to produce magnetic fields of 100 T to 700 T for microsecond durations in 11 to 16 mm bores.

More information about instrumentation, support services, and becoming a user is available on the Users pages of the NHMFL-Los Alamos web site at *http://www.mst.lanl.gov/nhmfl/welcome.html*, or by sending e-mail to *lacerda@lanl.gov*.

The NHMFL at the University of Florida, Gainesville

High B/T Facility

The NHMFL commissioned a high magnetic field and low temperature facility in 1997, known as the High B/T Facility. This facility provides researchers with the opportunity for studying phenomena that require simultaneous high magnetic fields and low temperatures. Current facilities provide 15.5 T with homogeneity of 50 ppm over 10 mm DSV and temperatures as low as 0.5 mK with a cooling capacity of the order of 10 nW. Values of the ratio of magnetic field to temperature up to 4 x 10^4 T/K will soon be available to users. Many new phenomena that require the establishment of high spin polarizations or high magnetizations, including nuclear magnetism, magnetokinetics, polarized quantum fluids, quantum-confined structures, and non-Fermi liquids, may be explored in this research facility. Some of the experiments planned with users in the near future include quantum Hall effect studies; determination of the upper critical fields for ordered phases in solid ^{3}He; and transport measurements for polarized dilute ^{3}He-^{4}He liquid mixtures.

Magnetic Resonance Imaging Spectroscopy

NHMFL user facilities for high field magnetic resonance imaging spectroscopy (MRI/S) are available in Gainesville. From the comprehensive list shown in the table, users might be particularly interested in the 125 MHz, 3 T, 0.1 ppm, 800 mm warm bore MRI/S magnet system, which has very fast imaging capabilities and is available for collaboration on functional, whole-body, imaging studies. Several planned improvements to the instruments have been ordered and should be available in the fall of 1999:

- An 89 mm bore, 750 MHz magnet for both spectroscopy and imaging.
- A cryoprobe for solution NMR in the 600 MHz, 52 mm magnet system.
- An 11.74 T, 40 cm bore spectrometer system for MRI/S.

UF Brain Institute

The NHMFL has established strong ties with the UF Center for Structural Biology and the UF College of Medicine and is consolidating its MRI/S efforts at the University of Florida Brain Institute that opened in 1998. The NHMFL user program can access 4.7 T, 33 cm and 3 T, 80 cm horizontal bore NMR imaging spectrometers, and 600 MHz, 5 cm NMR spectrometers. For more information, see *http://csbnmr.health.ufl.edu/facility.html.*

Nanofabrication Facility

Facilities are also available at UF for the fabrication and characterization of nanostructures at a new Nanofabrication Facility being operated in conjunction with UF's Major Analytical and Instrumentation Center (MAIC). The full capabilities of MAIC include:

- Atomic force microscope(AFM/STM)
- High-temperature x-ray diffractometer (XRD)
- Scanning electron microscope (SEM)
- Scanning transmission electron microscope (STEM)
- Electron microprobe (EMP)
- X-ray photoelectron spectrometers (XPS) (one dedicated to polymers and the other to high vacuum samples)
- Scanning Auger electron spectroscopy (AES)
- Energy dispersive x-ray spectroscopy (EDS)
- Electron energy loss spectroscopy (EELS)
- Secondary-ion mass spectrometer (SIMS)
- Ion backscattering spectroscopy (IBS)
- Ion scattering spectroscopy (ISS)
- Field ion microscopy (FIM)
- Digital scanning electron microscope
- High resolution transmission electron microscope
- High resolution x-ray diffractometer
- High vacuum scanning probe microscope
- Electron microscopy and microanalysis
- Electron beam lithography
- Particle induced x-ray emission
- Laser-plasma x-ray microscopy.

The NHMFL Proposal Review Process

As a national user laboratory, members of the worldwide science and engineering communities can access these facilities, generally without cost, through a peer-reviewed proposal process. Contact one of the people listed below for further information.

Continuous Field Facilities
Tallahassee, FL
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